Accounting for Localization Errors in a Mixed-Vehicle Centralized Control System

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Mixed Vehicle Scenario

- Near future will have vehicles with different levels of automation on the roads
  - Manually Driven Vehicles: No automation
  - ACC vehicles: vehicle control capability
  - CACC vehicles: vehicle control and communication capability
- Present day traffic issues → solution

  {Traffic jams, Accidents, Fuel economy} → Vehicle Control Coordination

Vehicle Control Coordination

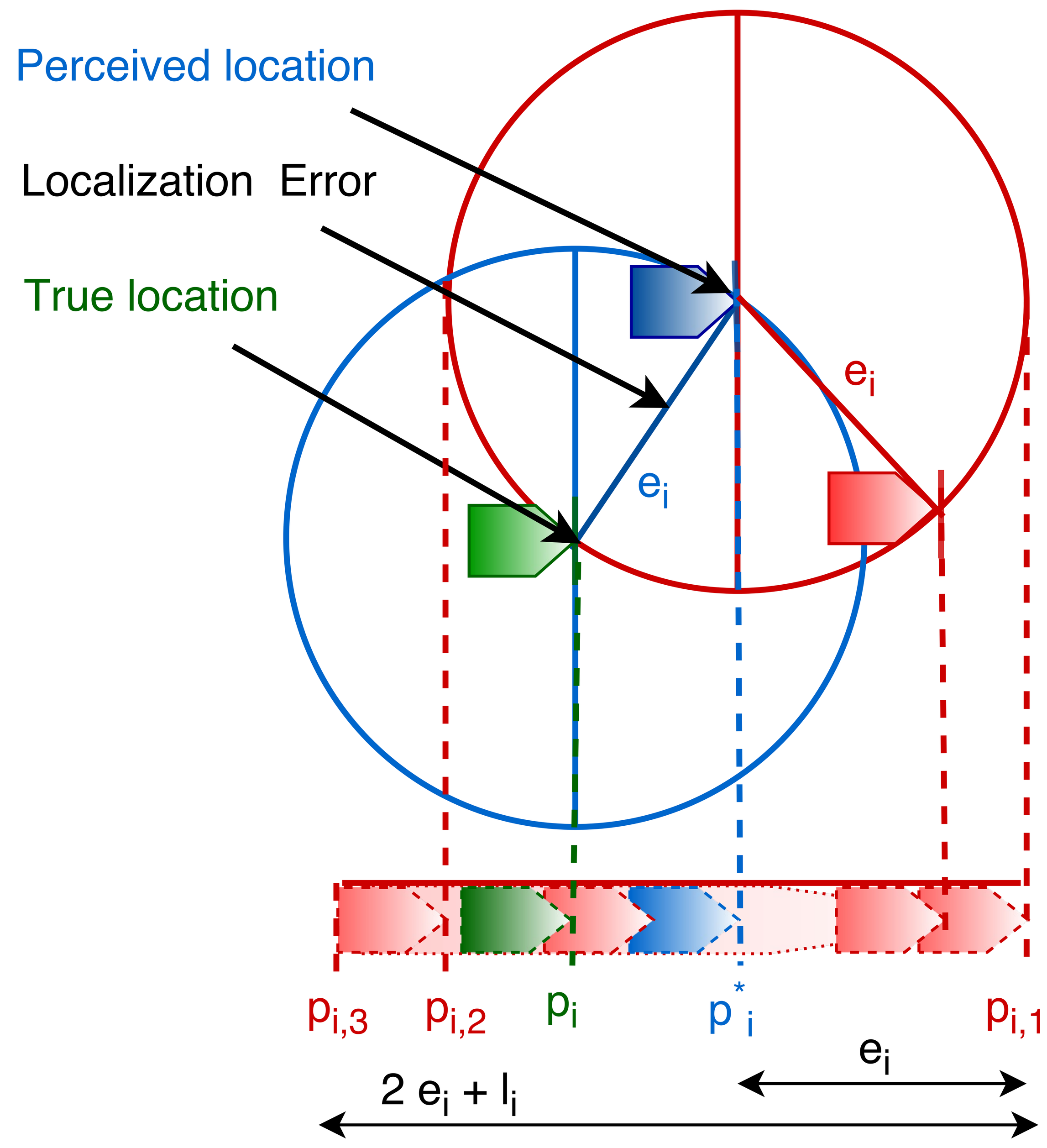
- Centralized control: a common controller computes and allocates control inputs
- From a controller point of view:
  Active Participants (APs) can be controlled (e.g.: CACC vehicles)
  Passive Participants (PPs) can not be controlled (e.g.: manually driven vehicles)
- Assumption: PPs like APs communicate with centralized controller using DSRC or cellular connection

Localization Errors

- Different Localization techniques achieve different levels of localization accuracy
- Localization errors with map-matching techniques are usually lower than with GPS
- Issue: Unaccounted errors in localization (e_i) causes accidents in a centralized control model

Methodology

- True location (p_i): (unknown) actual localization value
- Perceived location (p_i^*): (known) localization value with errors computed by the vehicle
- Potential location ($p_{i,1}$ to $p_{i,2}$): (computed) locations where vehicle can be found based on perceived location and localization accuracy
- Compute and use potential area occupied ($p_{i,1}$ to $p_{i,3}$) to ensure collision avoidance
- Solve multi vehicle collision free braking scenario using a centralized control model implementing Model Predictive Control



$p_{i,1}$ to $p_{i,2}$: Potential location of vehicle

$p_{i,1}$ to $p_{i,3}$: Potential area occupied by the vehicle

Figure: Modeling localization errors in 2D and in 1D

Centralized Control Model

Goal: To account for localization errors to ensure collision avoidance while deriving control inputs for APs

Cost Function $\left\{ \text{minimize } J = \sum_{i=1}^{n_v} \sum_{n=1}^{N} \| u_i(n) - u_i(n-1) \|_2 \right.$

subject to

State Equations
$$\begin{cases} l_{i,e} = l_i + 2 \cdot e_i \\ p_{i,1} = p_i^* + e_i \\ x_i = [p_{i,1}\ v_i]^T \\ x_i(n+1) = Ax_i(n) + Bu_i(n) \\ A = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix} \quad B = \begin{bmatrix} (\Delta t)^2/2 \\ \Delta t \end{bmatrix} \\ \dot{p_{i,1}} = v_i; \quad \dot{v_i} = u_i; \quad \dot{u_i} = j_i \end{cases}$$

Vehicle and Passenger Constraints
$$\begin{cases} x_i^{min} \le x_i(n) \le x_i^{max} \\ u_i^{min} \le u_i(n) \le u_i^{max} \\ j_i^{min} \le j_i(n) \le j_i^{max} \end{cases}$$

Collision Avoidance Condition $\left\{ d_{ik}^*(n) = p_{i,1}(n) - p_{k,1}(n) - l_{i,e} > 0 \qquad \forall i \in 2 \ldots n_v,\ k = i-1 \right.$

Braking Condition $\left\{ v_i(N) = 0 \right.$

Manually Driven Vehicles
$$u_i(n) = \begin{cases} 0 & \text{if } 0 \le n \le nt_{i,1} \\ u_i^{min} & nt_{i,1} < n \le nth_i \\ 0 & n > nth_i \end{cases} \qquad \forall i \in \{PP\}$$

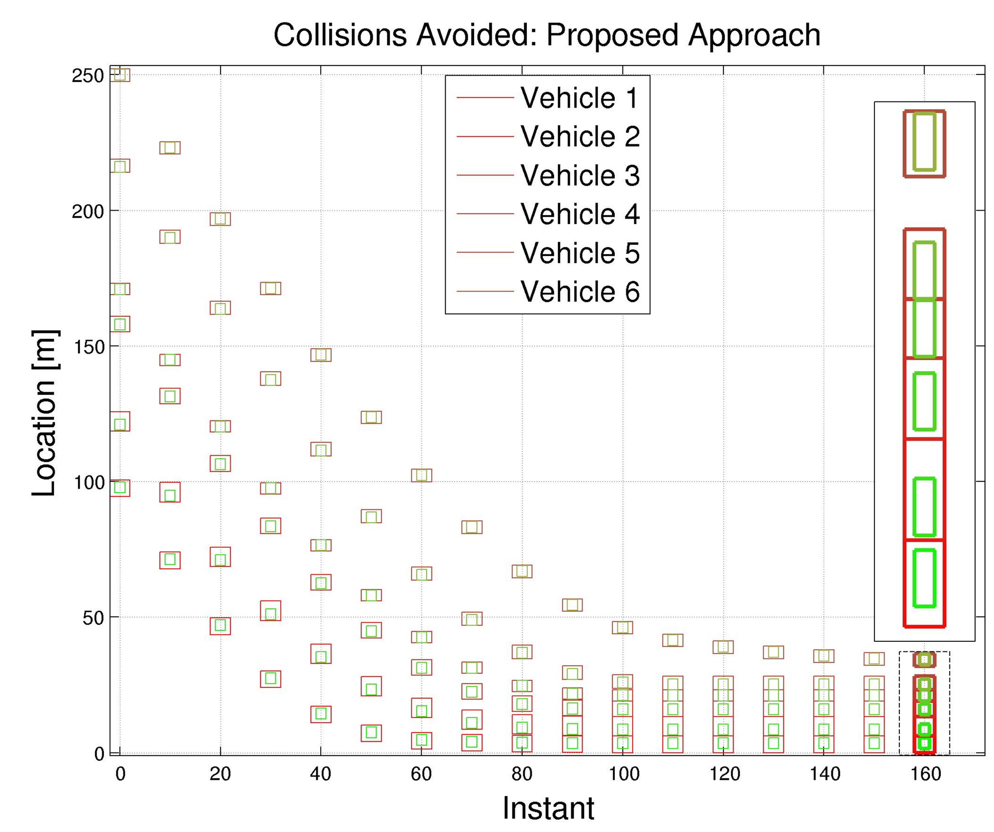
Evaluation Criteria

Compute number of collisions avoided when:

- Localization errors are absent ⇒ α
- Localization errors are present, unaccounted ⇒ β
  - compute control inputs using erroneous localization
  - implement computed control inputs on vehicles in their true locations
  - Cost function used in $\beta 1$ maximizes comfort whereas the cost function used in $\beta 2$ minimizes deviation from a desired intervehicular distance (3 m)
- Localization errors are present, accounted ⇒ γ

Algorithm Performance

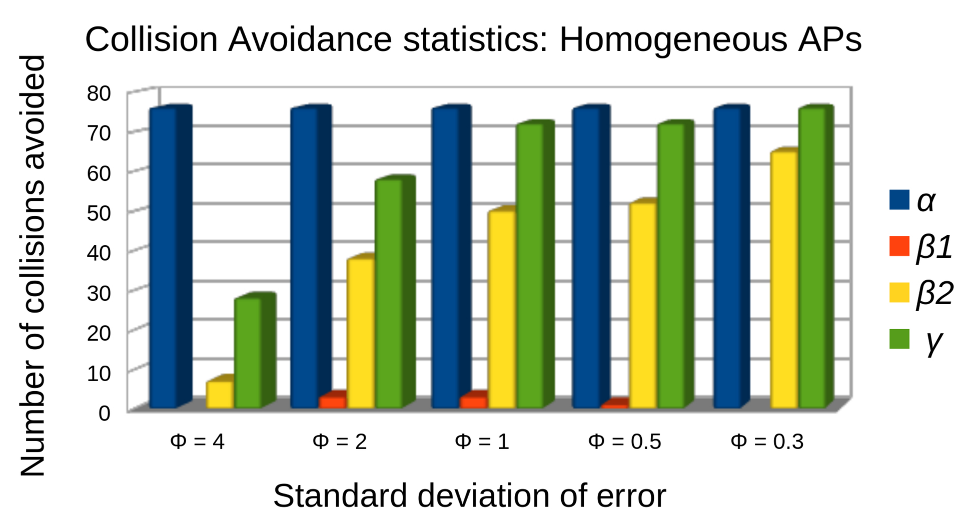
Green block = true location of vehicle
Red block = potential location of vehicle



Simulation Results

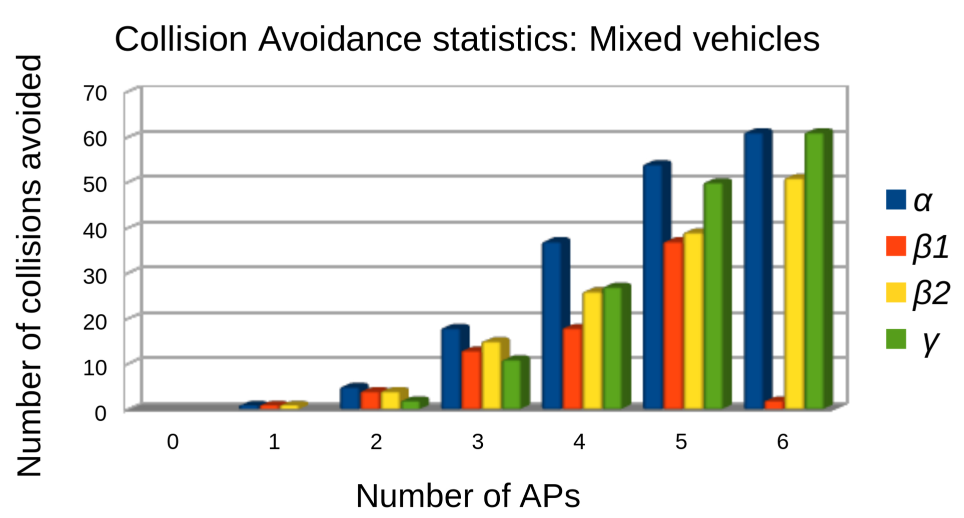
Homogeneous APs

- Localization error for each vehicle is derived from $\mathcal{N}(0,\ \phi)$ with a fixed ϕ



Mixed APs and PPs

- Localization error for each AP and PP is derived from $\mathcal{N}(0,\ \phi)$; (ϕ_{AP}=30 cm, ϕ_{PP}=4 m) respectively



Summary

- Our proposed approach considers localization errors while computing control inputs for APs in a centralized control system
- Despite erroneous localization, proposed algorithm closely matches the performance of the case where true localization was known
- Higher the penetration of AP, more are the collisions avoided because:
  - AP's controls can be controlled
  - AP's usually have lower localization errors

References

[1] R. H. Patel, J. Härri and C. Bonnet, "Accounting for Localization Errors in a Mixed-Vehicle Centralized Control System", MobilTUM 2017.